techcommentary

Electrotechnology Use for Drying of Modern Castable Refractories

Introduction

Today, gas and oil firing are the most common method of drying and heating of refractory lined ladles (Figure 1), tundishes, soaking pits and various furnaces (BOF, EAF and reheat) in steel mills. Convective heating for firing monolithic castable refractories can be achieved using one of several methods including the permanent burners in a furnace, waste heat from a nearby process, on-site dedicated burner setups for ladles and tundishes, or drying equipment especially designed by dryout contractors.

Electric resistance elements can also used for refractory drying and they offer several advantages that have led to their growing use in the Nordic countries. Power requirements for large ladles (steel ladles as large as 8 ft (2.4 m) in diameter x 10 ft (3 m) tall are not uncommon), can be very high. Resistance dryers can be from a few hundred to several hundred kW. One example of resistance refractory drying using three units resulted in electric consumption of nearly 0.5 MWh annually.

According to the 1998 AISI Steel Industry Technology Roadmap, the removal of the moisture associated with the installation of the material is the greatest challenge when working with monolithic refractory materials. While it is desirable to remove all the water as quickly as possible, if heating takes place too quickly, the surface will dry prematurely and prevent the underlying water from evaporating. The low porosity and permeability inherent in castable refractories can lead to lining damage and even explosive spalling from steam release. The Technology Roadmap states that, "Effective dewatering procedures based on gas, electric, or microwave heating must be established in order to fully realize the advantages associated with castable refractories."

This report reviews the various technologies for drying monolithic

Figure 1. Two designs of steel ladle, both of 75 tons (68 Mg) capacity.

refractories, the types of refractory materials used, and the methods for installing these refractories. The equipment used for resistance heating for the drying process that has been applied outside the U.S. is also reviewed. However, the application of other electrotechnologies, such as microwave and infrared heating, are not addressed. No commercial applications have been identified and it appears that further system development and testing will be required before these technologies are commercially accepted.

Drying of Monolithic Refractories

To avoid lining damage and achieve optimal performance, suppliers of lining material have provided heating curves that
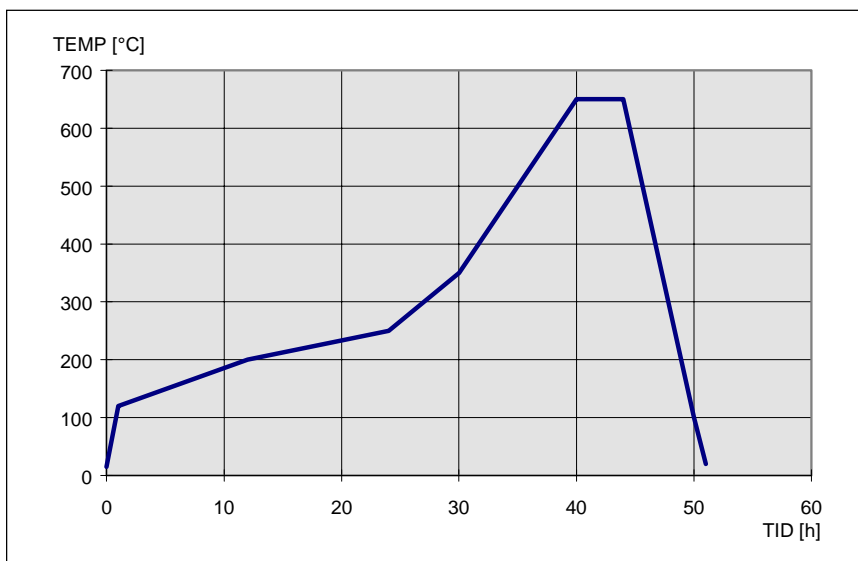

Figure 2. Example of heating curve for drying monolithic material.

must be followed throughout the drying process. An example is shown in Figure 2.

Heating or firing castable refractories after installation is commonly referred to as "dryout" but there are actually several stages associated with this process:

Curing

The immediate period following installation of the refractory material. For conventional castables, a hydraulic bond is formed usually in 24 hours or less at ambient temperature. The environment, and in particular the temperature during installation and curing, has a profound influence on the displacement of chemically combined water.

Dryout

The removal of sufficient quantities of moisture from the refractory hotface at some elevated temperature to allow the main furnace burners or process to be started.

Bakeout

A period at elevated temperature in which the formation of chemical bonds in the refractory is accelerated. The bakeout period is particularly important for plastic or moldable refractories.

Heatup

A continuation of the time and temperature of heating to bring the refractory to the operating temperature of the furnace or vessel. Final heating is a process in which the dried lining material is quickly heated to a temperature high enough so that no damaging heat stresses occur when the equipment is placed in service. In the iron and steel industry, the final temperature is normally about 1,200°C. It is not a good practice to cool a furnace or vessel after heatup in order to determine if any cracks have developed in the refractory. A cooldown of the refractory in this case is always more detrimental than a heatup.

The dryout schedule will vary due to differences in refractory permeability, density and thickness. For the traditional high cement content calcium aluminate castables (CACs), the critical hotface temperature is between 360°C to 500°C. Most of the chemically combined water is released when it dissociates between 200°C to 330°C. As the temperature rises,

it is speculated that the vapor pressure towards the hotface becomes so high that it forces any newly released water toward the coldface. Explosive spalling can occur when the 360°C to 500°C temperature range has moved several inches into the lining creating a stress gradient between the drier hotface and wet coldface. Traditionally, to prevent this occurrence, a temperature hold at 300°C to 350°C and also at 550°C or 650°C is called for in dryout schedules of conventional CACs. However, some practitioners are now

advocating a steady, transitional heating rate through these temperature ranges.

Most of the heating curves for refractory drying are based on drying using fossil fuel firing. The highest drying temperatures are usually between 450 and 750°C and drying times normally vary between 50 and 70 hours. In such cases, it may be possible to reduce the time using electric heating, but this must be explored in consultation with the supplier of the lining material

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Bonds...Refractory Bonds

Bonds must be formed in monolithic refractories to hold the molded or formed shape after installation. The bonds formed in monolithic refractories are one of three types: hydraulic, ceramic or mineral. These bonds are initiated during installation and completed in service.

- A **hydraulic** (chemical) cement-like silicate or aluminate bond, which involves setting and hardening at room temperature when water is added. Heating to a high temperature destroys the weak hydraulic bond but attains a stronger ceramic bond.

- A **ceramic** (physical) bond, somewhat present at room temperature, which fully develops upon firing.

- A **mineral** (chemical) phosphate bond which involves hardening above room temperature (typically to 150°C) but below sintering temperature.

The hydraulic bond is the most common in modern castables. Reacting with water, the **calcium aluminate castables** (CACs) form hydrate phases that set and harden at room temperature.

Conventional castables contain a high proportion of cement (CaO), typically 15%-20%. The water content is 8%-15% to allow the hydration products to form and to give suitable rheology for casting. The stronger ceramic calcium aluminate bond develops upon heating the material to 900°C to 1,000°C. However, the porosity

resulting as the water is removed is high, approaching 25% porosity by volume. In conventional castables, strength depends directly on the amount of cement added to the composition. However, increasing cement quantity to achieve higher strength requires more water, creating more porosity. Although low temperature properties improve with increasing cement content, intermediate- and high-temperature properties do not.

A newer trend is the use of refractory binders based on "sol gel" technology. An example is the use of colloidal silica (Gel-Bond) in castables, replacing CAC, providing all the advantages of the LCC and ULCC, while eliminating most of the disadvantages. Colloidal silica gels around the refractory particles. After drying, the skeleton derived from the gel holds the particles together and provides the initial strength. This "zero-cement" technology, brought **pumpable refractories** to the marketplace in 1989.

The latest trend in monolithic refractories has been in formation of *in situ* or *self-forming* bonds, e.g., the formation of cubic spinel from MgO (75-85%) and Al_2O_3 (10-15%) matrix components. The useful magnesium aluminate oxide refractory is formed in-service by reaction of the lining with the constituents or phases within the refractory itself. **Alumina-spinel castables** are used increasingly in steel ladles, concast tundishes, and degasser snorkels and lances.

Monolithic Refractory Materials

Monolithic refractories are characterized by their formation as a single mass of shaped refractory material (without joints or seams) as opposed to building up a shape using individual bricks or panels. Monolithics are in common use today and include:

Low-cement castables (LCCs) contain no more than 5% CaO. The corresponding lower water content makes LCCs easier to dry. Lower water content also reduces porosity to 8%-15% yielding higher strength and reduced permeability to aggressive liquids and gases. LCCs have properties comparable to brick but lose their hot strength appreciably when temperatures rise significantly above 1,500°C.

Some LCCs cannot be cast because of their low water content, but are thixotropic and can only be compacted by vibration. Other LCCs, such as **self-flowing castables** (SFCs), will flow without vibration and with only 4.5%-8% water addition. These SFCs can be installed in 8-24 hours and are increasingly used to line low wear areas of steelmaking vessels.

Ultra-low-cement castables (ULCCs) with CaO between 0.2% and 1% have improved hot strengths over LCCs and some refractory brick. When used with Al_2O_3 aggregates, these refractories provide high bonding strength up to 1,800°C.

Zero-cement pumpables have advantages over CACs including less mixing time, less drying time (95% of the water is repelled within 24 hours at 110°C compared to 60% for the cement bond), higher hot strength, better thermal shock resistance, lower thermal conductivity, and better oxidation resistance. They have been successfully used in blast-furnace cast-house troughs, iron and slag runners, torpedo ladles, tundish back-up linings, flow control shapes, and electric furnace deltas and runners. They have also been extremely successful in secondary operations such as reheat furnace hearth, sub-hearth, and soaking pit hearths. In foundries, they have been used in coreless induction furnaces, in the iron-well and transfer troughs, in stirring beams and in transfer ladles.

Methods for Installing Monolithic Refractories

The primary methods for installing refractory linings are:

*   **Casting** (a dry mix, which, when mixed with water, can be shaped by casting or vibrating),
*   **Gunning** mixes (free flowing mixtures specially made for installation by pneumatic or mechanical projection), and
*   **Ramming** or molding a plastic "clay" form of refractory.

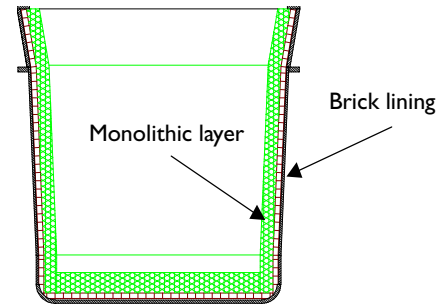Initially, monolithic refractories were used for repair or in less-severe service

Figure 3. Section of a 110-ton monolithic steel ladle. Between the monolithic lining (green) and the mantle is a backing of refractory brick.

applications, but they now account for 60% of refractories production and are used in almost all areas of furnace and transfer vessel linings. This increased use has been primarily due to the development of monolithic refractories with decreasing cement content and zero-cement technology (pumpable).

Refractory linings usually incorporate an outside layer of refractory brick, even when using monolithic refractories (Figure 3). According to authors Lee and Moore, "Evolution of *in Situ* Refractories in the 20th Century", the most fundamental change over the past 25 years associated with manufacturing technology for refractories has been the installation procedures for monolithics. Moldable (a.k.a. plastic or rammable) refractories are put into place by hand and compacted using mechanical devices. Dry magnesia-based tundish linings, a popular
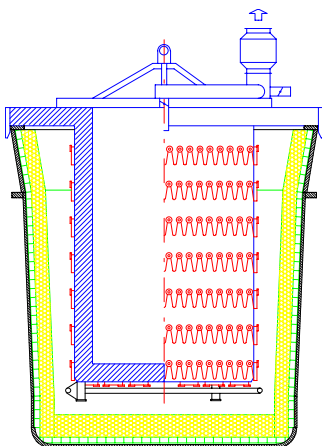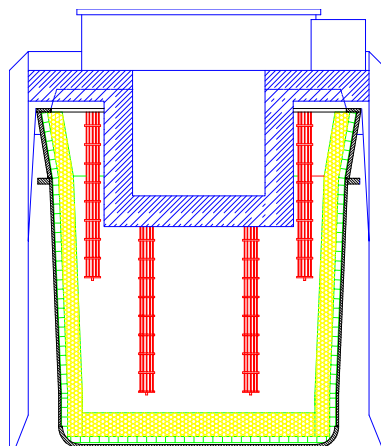
Figure 4. Radiation heater made by Sarlin.

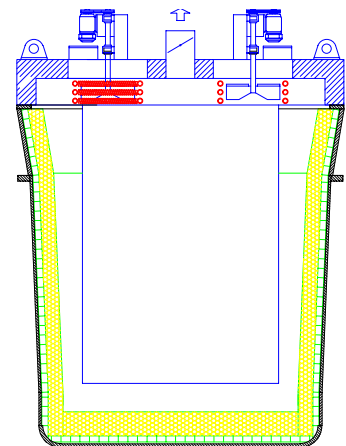**Figure 5. Radiation heater made by Tech.**

Figure 6. Convection heater made by UTAB.

belts. The heating elements are placed around each fan wheel. Heat is transferred mainly through convection. The underside of the cover has a sheet steel cylinder of cortén.

Heating elements of the Tubothal type made by Kanthal are an alternative to the silicon carbide elements most often used by Tech. Tubothal elements are constructed of APM wire on ceramic supports (Figure 10). Tech has used Tubothal and has concluded that these must not be longer than 1 meter for use in ladle heating. The reason is that the aluminum in the APM wire oxidizes, creating aluminum oxide that is very hard. The aluminum oxide cracks when the temperature fluctuates. New oxide then forms in the cracks, causing permanent elongation. The friction against the ceramic supports causes these to crack after a time if the total length of the element exceeds 1 meter.

A complete equipment set for electric drying and heating of ladles consists of the following components:

- Heater complete with elements, possibly fans, temperature transmitters, etc.
- Handling equipment, such as a motorized frame
- Trolley for handling the ladle
- Flexible cables between heater and connection box
- Connection box for flexible/fixed cables
- Fixed cables between connection box and control equipment
- Electrical equipment for temperature control and monitoring
- Power supply for the control equipment

The heater is mounted on a frame with a vertically movable platform. The platform is operated hydraulically, pneumatically, or by a motor. The ladle stands on a trolley that is rolled into place on rails under the heater. The trolley for handling the ladle is designed so that the ladle is always placed in the same position in relation to the heater. Since the heater is movable, the cables to the heater must be flexible. These cables must naturally be as short as possible. It is therefore often advisable to install a connection box near the heater where the flexible cable is joined to fixed

cables connected to the electrical equipment.

The electrical equipment is provided with one or more temperature regulators that control the power via thyristors so that the desired temperature curve is obtained. The temperature transmitter(s) for control purposes (one per regulator) are usually installed both in the center of the heater and near the floor of the ladle. Thus, it is the air temperature in the ladle that controls the power input. In addition, an overheating sensor is included whose transmitter and signal converter should be completely separate from the control equipment.
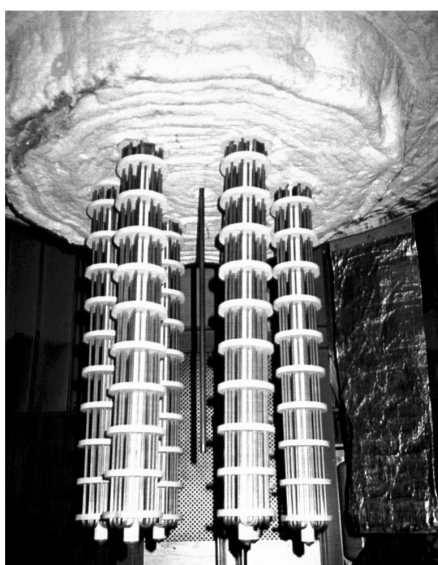

Figure 10. Elements of the Tubothal type (Kanthal).

Microwave Heating

The Japanese have used microwave heating for drying of steel mill refractories. T. Kayama of Nippon Steel Corporation (Futtsu, Japan) reported on the use of a microwave drying system to dry monolithic refractories of steel teeming ladles at the American Ceramic Society's annual meeting in Indianapolis in 1994. Also, Kiyoto Kasai reported (in Nippon Steel Technical Report No. 61, April 1994) that, "The largest problems with the use of monolithic refractories are long drying time and steam explosion. These problems are successfully coped with by developing a drying unit that uses microwaves and hot air in combination, and commercializing a short-time and steam explosion-free drying technique."

No other users of monolithic refractories have reported on the use of microwave heating for drying of the refractory.

Competing Processes

For many furnaces, the permanent fossil fuel burners cannot be operated with proper temperature control (turndown ratio) or proper uniformity at the low temperatures required for refractory dryout. Sometimes, waste heat is not available for drying refractories, either for furnaces or transfer/holding vessels such as ladles or tundishes. Auxiliary fossil-fired equipment consists of a half dozen light, portable burners, separate combustion air blowers, controller consoles with ultraviolet flame sensors, associated fuel and air hosing, and electrical cable connections. Useable fuels are natural gas, propane or butane and all the light distillate oils (Figure 11) such as #2 oil, diesel or kerosene.

In any case, most of the chemically bound water is driven to the coldface and collects at the bottom of the furnace cladding or vessel. Free-water release denoted by high-pressure steam jets from the hotface calls for a hold in the heatup until the steam jets subside. The temperatures referred to in dryout schedules should be the temperature of the convective gases in contact with the hotface, and not of the refractory itself. One popular fuel-fired technique for refractory dryout involves maintaining the bottom of the vessel or furnace under a positive pressure. This floods the area with hot air and inhibits the ingress of cold air.

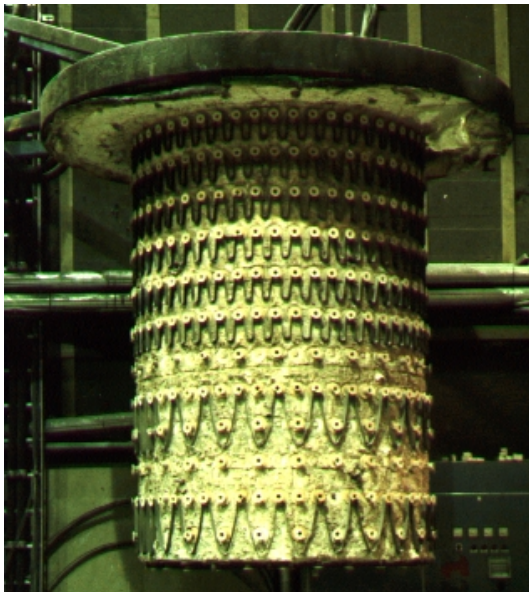**Figure 11. Oil-fired Ladle Drying Setup.**

Figure 7. Sarlin radiation heater at Fundia Wire, Koverhar, Finland. Total output 300 kW.
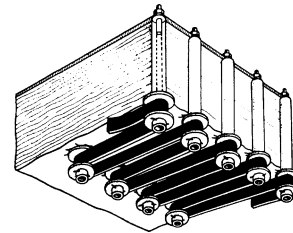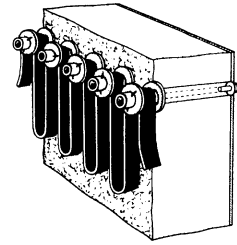

Figure 8. Principle for mounting strip elements on the mantle side (top) and floor (bottom).

alternative to sprayed magnesia linings, are poured into the space between refractory brick and a mold (formwork) and vibrated to achieve settling and proper consistency. Casting is similarly performed, only without the need for vibration. One disadvantage of shaping by casting or vibrating is the need for this expensive and cumbersome formwork which establishes the hot face of the castables. On the other hand, this is still preferable to tedious bricklaying.

In the 1960s, castable manufacturers developed systems with minimum rebound so that they could be gunned in place. Rebound is the loss of refractory material due to it bouncing off of the surface being gunned. In the dry gunning process, the water is mixed with the powder batch in the gun nozzle. In the wet gunning (shotcreting) process, the raw material and water are premixed and, under pressure, projected into place through a nozzle. Typical rebounds range from 15%-30% for dry gunning to 0% for shotcreting. Other variations include plastic gunning (using shredded moistened materials) and hot/flame gunning where material is partially melted and projected into place via a lance. Shotcreting has been widely applied to refractories because of the need to reduce dust emissions, the relatively high levels of rebound in dry gunning, and the elimination of expensive casting forms.

Electrotechnologies for Drying Monolithic Refractories

Resistance Heating

Electric ladle heaters may be designed as radiation heaters or convection heaters. Power levels range from 100 kW to 500 kW depending on the size of the ladle. Design examples are shown in Figures 4, 5, and 6.

The Sarlin radiation heater (Figures 4 and 7) can be regarded as an external and internal bell furnace and consists mainly of a fiber insulated cylinder with a floor and cover. The external diameter of the cover is somewhat larger than the external diameter of the top of the ladle. The cylinder mantle is completely clad with resistance elements in the form of strips suspended on ceramic supports, generally as in Figure 8 (top). Similar strips are mounted along the edge of the cylinder floor, as shown in Figure 8 (bottom). The center of the floor has no resistance elements.

Radiation heaters made by Tech (Figures 5 and 9) mainly consist of an insulated cover, the underside of which is provided with a number of heating elements. These may be of silicon carbide or resistance wire. A ladle heater from UTAB (Figure 6) has an insulated cover with three fan heating units. The fans are driven via

Figure 9. Radiation heater made by Tech, equipped with elements of silicon carbide. The heater is installed at Sauda Mangan in Norway.

Electric Drying Advantages

Convective heating for drying refractories has a very low efficiency, about 5-8%, since large amounts of (cold) air are consumed in combustion. Most of the heat is dissipated with the outlet gases. It is very difficult to achieve satisfactory temperature control, especially at the low temperatures that occur when starting the drying cycle.

In addition to the low thermal efficiency, the environment is affected negatively, with large emissions of CO_2, NO_X, SO_2, particulates, and considerable noise. Electric resistance ladle heaters for drying refractory have been used successfully in a half dozen Nordic steel mills since 1990. Replacing fossil fuel firing with electric heating may reduce operating costs and also offers various other advantages such as:

Improved quality and life of lining

- Simple and accurate temperature regulation
- Considerably reduced energy consumption
- High availability
- Greatly reduced need for attention during normal operation
- Greater safety for personnel and equipment
- Reduced maintenance need

Summary

Although electric resistance drying has not yet penetrated the U.S. market, it is being used overseas. The trend toward low-cement castables and zero-cement pumpables has significantly decreased the water content of monolithics making electric drying technologies more applicable and competitive. The low efficiencies and resultant large energy usage by fossil-fueled refractory drying represents an attractive load growth opportunity for electric utilities.

Sources used in this issue of *TechCommentary* include:

John Danelius "General Description of Electric Ladle Heating and Final Heating - For the Iron and Steel Industry" Vattenfall 96-JS-0091, December 1996

Norman W. Severin "Refractory Dryout - How Can We Improve It?" *Canadian Ceramics*, February 1998

Subrata Bannerjee "Recent Developments in Monolithic Refractories" *The American Ceramic Society Bulletin*, October 1998

William E. Lee and Robert E. Moore "Evolution of in Situ Refractories in the 20th Century" *Journal of the American Ceramic Society*, Vol. 81 [6] 1998, pp. 1385-1410

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